REMOTE SENSING APPLICATIONS IN FORESTRY

THE USE OF MULTISPECTRAL SENSING TECHNIQUES TO DETECT PONDEROSA PINE TREES UNDER STRESS FROM INSECT OR PATHOGENIC ORGANISMS

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Annual Progress Report 30 September, 1968

A report of research performed under the auspices of the

FORESTRY REMOTE SENSING LABORATORY,
BERKELEY, CALIFORNIA—

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For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Frontispiece.--Oblique color photo (Anscochrome D/200) of ponderosa pine trees being randomly killed by the Black Hills bark beetle, near Lead, South Dakota. Small infestations of two to five discolored trees (as indicated by arrows) are symptoms signalling the beginning of an epidemic. Part of the work reported herein is designed to learn the smallest scale of aerial photography that can be used to detect such epidemics.

ABSTRACT

The objectives of this study are twofold: one, to determine what airborne sensors may be used to detect and map the presence of dying conifers before visual symptoms occur, and, two, to establish what the smallest scale of aerial photography may be to detect insect epidemics from space altitudes.

The first phase of this study was reported on in detail in the two previous progress reports. Again, during the 1967-68 season, biological and meteorological measurements were made to relate the "ground truth" to aerial imagery. Not only were large-scale color photographs taken but also imagery was produced by the 17-channel optical-mechanical scanner from the Willow Run Laboratories, University of Michigan.

A pilot test was conducted on a three-square-mile area to simulate conditions expected from space photography. Color and infrared color transparencies were produced at the following scales: 1:116,000, 1:63,360, 1:31,680, 1:15,840, and 1:7,920.

Dying pine trees were again measured to be up to 6° C. warmer than healthy trees during early afternoon in May. This substantiates data gathered during the same month in 1966 and in 1967. Imagery from the Michigan flights is not available yet for analysis and reporting purposes. Because 1968 was a drier year than 1967, dying foliage was more yellow-red than for the same month the previous year.

Photo interpretation of large-scale transparencies (1:1,584) showed best results when foliage was most discolored in August.

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The purpose of this study [illegible] to determine what airborne [illegible] may be used to detect and map the presence of [illegible] before visual symptoms become apparent, and to determine what the [illegible] of [illegible] to detect the [illegible] from aircraft altitudes.

The third phase of this study was [illegible] on the [illegible] progress reports. Again, during the [illegible] season, [illegible] measurements were made to relate the [illegible]. [illegible] of [illegible] taken [illegible] was [illegible] from [illegible] Laboratories, University of Michigan).

[illegible] was conducted on [illegible] with [illegible] obtained from [illegible] photography. Color and infrared color photography were obtained at the following scales: [illegible].

Dying pine trees were again measured to be up to [illegible] C. warmer than healthy trees during early afternoon in May. This substantiates data gathered during the same month in 1966 and in 1967. Imagery from the Michigan flights is not available yet for analysis and [illegible]. Because 1968 was a [illegible] year [illegible], foliage was more [illegible] than [illegible] the same [illegible] the [illegible] was [illegible].

[illegible] of [illegible] (1967) [illegible] that [illegible] when foliage was [illegible].

As in 1966 and 1967, color transparencies were as effective in detecting dying trees as color infrared transparencies. Again, neither film was an effective previsual sensor.

On the pilot study area, as the images became smaller (smaller scale) and as the size of the infestation became smaller, photo interpretation accuracies decreased.

For the greatest accuracy, we found that entomologists need a scale of at least 1:7,920 to detect the presence of a new epidemic which usually manifests itself in small infestations of 1 to 3 trees (5 to 20 feet).

Detection on 1:15,840 scale photography is only slightly less successful than on the 1:7,920 scale. With the exception of small infestations, 1 to 3 trees in size, a 1:31,680 scale will result in detection almost as good as on larger scales, at much less cost. Infrared color film is better than color for detecting small infestations on these three larger scales.

ACKNOWLEDGEMENTS

This experiment is being performed under the Earth Resources Survey Program in Agriculture/Forestry under the sponsorship and financial assistance of the National Aeronautics and Space Administration, Contract No. R-09-038-002. This is the third progress report of a cooperative study with the Forest Service, U. S. Department of Agriculture. The study involves two Forest and Range Experiment Stations and one Region: the Pacific Southwest at Berkeley, California; the Rocky Mountain at Fort Collins, Colorado; and Region 2, Denver, Colorado. Salaries of all professional employees are being contributed by the Forest Service.

We wish to thank the Homestake Mining Company, Anaconda Copper and Mining Corporation, and the Bureau of Land Management, U. S. Department of Interior, for the use of their land and timber to conduct the study.

The Spearfish and Nemo District Rangers of the Black Hills National Forest have been very helpful in providing vehicles, darkroom facilities, and field equipment.

We would like to acknowledge the continued high quality workmanship of Richard Myhre, our research forestry technician, in producing excellent quality aerial films and photos used in this report and to recognize Wallace Greentree, forestry technician, for his supervision of the photo interpretation and the tedious data reconciliation and summation involved in this report.

We thank the three photo interpreters, Greg Burnside and Shari Wall from the School of Forestry and Conservation, University of California at Berkeley, and Jeffrey Linton from the Pacific Southwest Forest and Range Experiment Station, Forest Disease Research Project, Berkeley, California, for their careful and diligent study of all aerial photography.

Finally, we would like to acknowledge the assistance of Fred Stang, Barnes Engineering representative in Santa Clara, California, and his loan of the PRT-10 (portable radiation thermometer) during our test in May.

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THE USE OF MULTISPECTRAL SENSING TECHNIQUES TO DETECT PONDEROSA PINE TREES UNDER STRESS FROM INSECT OR PATHOGENIC ORGANISMS

by

R. C. Heller, R. C. Aldrich

W. F. McCambridge, F. P. Weber and S. L. Wert

INTRODUCTION

This study is a continuing one aimed at the previsual aerial detection of coniferous trees under stress from bark beetle attack. Our goal is to find which wavelengths or combination of wavelengths in the electromagnetic spectrum (EMS) will differentiate healthy from dying pine trees. After this determination, problems to be solved are to find the optimum altitudes for sensing with various films and filters or with electronic scanners--including airborne infrared and side-looking radar.

This is the third annual progress report detailing the work which was undertaken from September 1967 to the present. The two earlier reports (September 30, 1966 and September 30, 1967) summarize the importance of the problem to forest managers and also the biological and physical phenomena which are involved and were investigated. These reports point out that both aerial photography, using color and infrared color films, and thermal sensing scanners were incapable at that time of detecting previsual symptoms of dying pine trees. We did learn a great deal on the ground during these three seasons about the reflectance and thermal patterns of living and dying coniferous trees

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PONDEROSA PINE [illegible] UNDER STRESS [illegible]

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by

[illegible], R. C. Albright

W. M. McCambridge, [illegible] F. Weber and S. L. Hart

INTRODUCTION

This study is a continuing one aimed at the [illegible] detection of conditions trees under stress from bark beetle attack. Our goal is to find which parameters or combination of parameters in the [illegible] (2-14 [illegible]) will differentiate [illegible] from dying pine trees. After this determination [illegible] solved one to find the optimum altitudes for sensing with [illegible] films and filters [illegible] — [illegible] and [illegible] making [illegible].

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that we could expect to exploit with airborne sensors. Until this season we have been unable to get suitable airborne instruments over our test sites at the proper time periods. We did get four flights (26 runs) in May over the Lead, South Dakota, test site with the 17-channel multispectral scanner from the Infrared and Optical Sensor Laboratory of the University of Michigan. We do not have the imagery or playback tapes at this time, but will report on the results as soon as possible.

A short summary of the various ground instruments used during this growing season is listed later in this report under GROUND PROCEDURES. Some of these instruments and procedures are described in more detail in the earlier reports, but several refinements were made this season.

We also tested very small-scale aerial photography (1:116,000) to learn the smallest scale that might be tolerated for use in making forest management decisions during forest insect epidemics. The implications for space resource photography are quite apparent and are reported under RESULTS.

LOCATION OF STUDY AREAS

Two study areas were selected within two miles of each other near Lead, South Dakota, in the Black Hills National Forest (Fig. 1). One study area (Study Area I) is within one-quarter mile of the attractant sites used in 1966-67. At this area, five beetle (Black Hills beetle [*Dendroctonus ponderosae* Hopk.]) attractant sites[1] were established by entomologists from the Rocky Mountain Forest and Range

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[1] An attractant site may be defined as an artificially established bark beetle infestation.

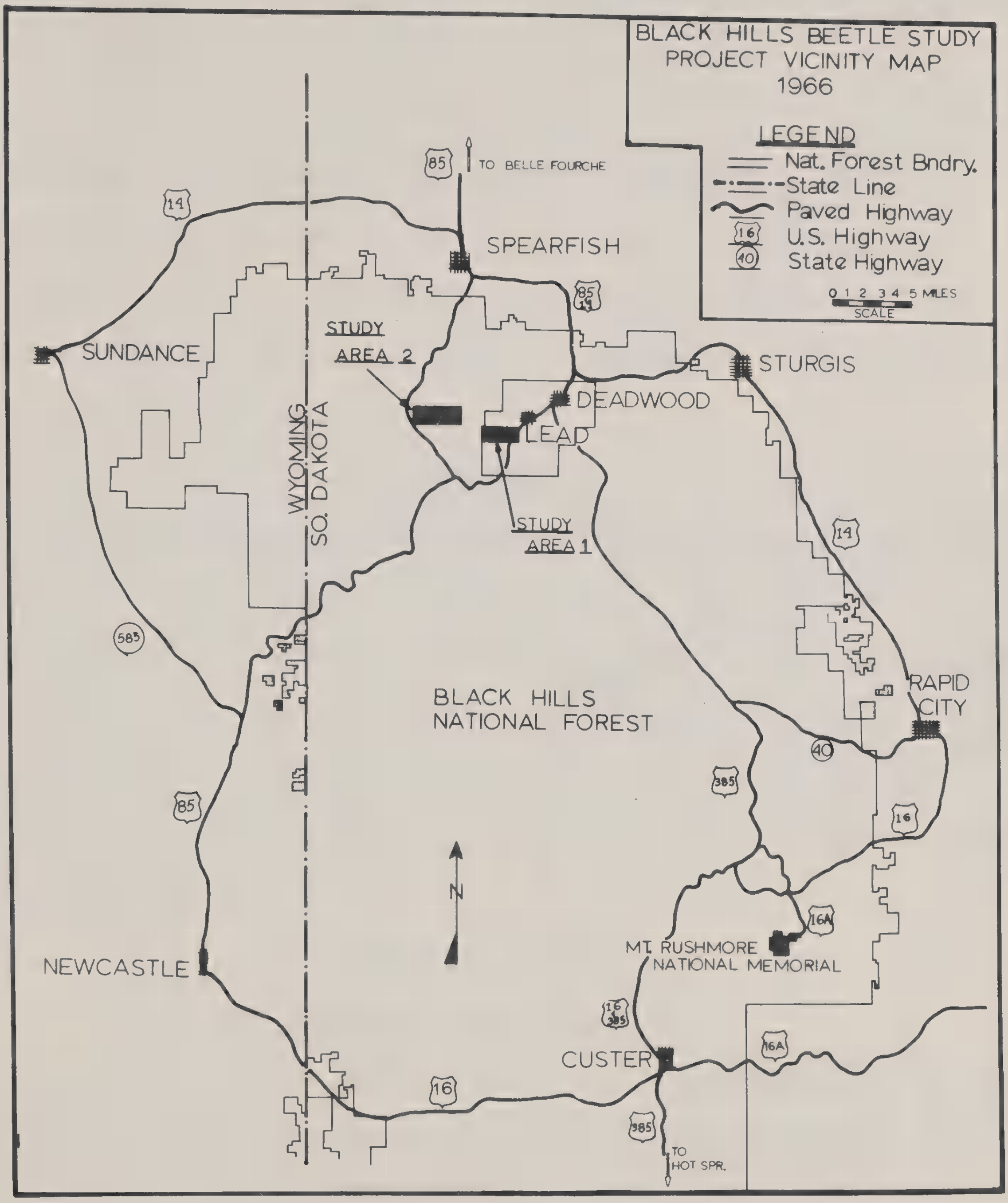


Figure 1.--Study Areas I and II near Lead, South Dakota. Study Area I is near site of previous tree biological and thermal sensing studies. Study Area II represents an area where beetle epidemic conditions exist and where tests were conducted to determine the likelihood of using space photography to detect the damage.

Experiment Station (Fig. 2). The detailed physiological and thermal data were collected on one attractant site at this area.

The second study area (Study Area II) was selected to represent tree damage conditions existing during a typical beetle epidemic (FRONTISPIECE). It covers about three square miles and required extensive aerial plotting on existing photographs and ground examination to determine the "ground truth." It served as the test area for the simulated space photography.

METHODS

We again monitored meteorological, physical and physiological interactions on Study Area I so that we could relate our ground data with the airborne imagery. Only a brief listing of what factors were measured will be discussed under the next section. The reader is directed to the two earlier progress reports for details of instrumentation and techniques used. Only improvements or changes will be discussed.

GROUND PROCEDURES

On attractant sites--Study Area I

In August 1967, McCambridge again induced bark beetle attack by placing 300 virgin female beetles in screen cages attached to the host ponderosa pine (*Pinus ponderosa* Laws.) trees. At each attractant site we determined the beetle population and plotted on a plane table the following numbers of attacked trees:

Figure 2.--Kodak Ektachrome Infrared Aero (Type 8443) stereo photograph of attractant site 67-3 (August 17, 1968). Note 70-foot weather tower in lower center of picture erected for making meteorological measurements. Healthy pines appear red, pines with yellow (10Y to 5Y) foliage appear pink to white, pines with yellow-red (10YR to 7.5YR) foliage appear yellow on this film. The reader may get the advantage of stereoscopic viewing by placing a lens stereoscope over any two adjacent (overlapping) photographs.

Site Number	Number of Trees Attacked	Average Number of Beetles/sq. ft.*
67-1	52	91
67-2	20	90
67-3	32	43
67-4	28	126
67-5	5	No data
Total 5	137	

* Average of 5 trees each site; 2 samples per tree

Biological and Physical Data Collection

All physiological and meteorological measurements were taken on trees at attractant site 67-3 (Fig. 2). Two weeks prior to the expected airborne flight, two men began establishing the ground instrumentation. As mentioned earlier, only a few techniques will be discussed in detail; however, a listing of the factors measured and the instruments used are listed as follows:

Factor	Instrument
1. Foliage discoloration	Munsell charts
2. Temperature	
a. Internal needle	Thermocouples to Honeywell Multipoint Recorder
b. Ambient	Belfort Hygrothermograph Four aspirated thermocouples
c. Emitted (Radiometric)	Radiation thermometers-Barnes PRT-5, Stoll-Hardy HL-4 (modified)
3. Transpiration (sap flow)	Sap flow detector
4. Leaf moisture stress	Hydrostatic pressure bomb
5. Solar radiation	Belford pyrheliometer
6. Wind velocity	Beckman-Whitley (light-chopping) recording anemometers
7. Humidity	Belfort Hygrothermograph
8. Spatial resolution	8 x 68 foot aluminum and black target--in panel widths of 2, 4, and 8 feet

A 70-foot weather tower served as a base for collecting solar radiation, wind speed and emitted (radiometric) temperature data.[2] Two healthy trees and four attacked trees were instrumented for measuring internal water movement, internal needle temperature, and needle moisture tension.

Test trees were chosen as representative individuals in the stand. They were either dominant or codominant in crown position and had a mean height of 62 feet.

Foliage emission temperatures, which were measured with both a Barnes PRT-5 radiation thermometer and a Stoll-Hardy HL-4 radiometer, continue to be an important measure for evaluating the success or failure of an airborne thermal detection system. Radiometers measure the same emitted temperatures which should be "seen" by low-flying thermal scanners. In this case, radiometer data of tree temperatures were important for setting the upper and lower temperature limits for the thermal reference plates on the Michigan thermal scanner.

Barnes Engineering Company loaned us one of their new PRT-10 (portable radiation thermometer) instruments for trial under field conditions (Fig. 3). It is extremely light in weight and handy to use in the field. The instrument can be calibrated by a thermometer which is furnished. We noticed that the temperature readings vary considerably according to the angle at which the instrument is pointed and also the distance between the sensing head and the object for which

[2] Emitted temperatures referred to hereafter in this report are apparent emitted temperatures obtained with radiation thermometers of emitted energy above 3.5 microns.

Figure 3.--A Barnes (PRT-10) portable radiation thermometer was used at the resolution target to record apparent emitted temperatures. The photo at left indicates manner in which temperature readings were taken a fixed distance above aluminum and black surfaces of resolution target. The right photo shows temperature indicator in °C. with instrument pointed at bare soil. Knob on right side of instrument is used for calibration.

the temperature is required. We suggest that a small stand be built to hold the detecting element at the same angle and distance away from the object of interest.

At the time of the multispectral flight in May, the PRT-10 was used to measure apparent temperatures over the resolution target (black and aluminum surfaces), bare soil, and grass.

<u>On large study area - Study Area II</u>

In mid-August, a beetle-infested area about one by three square miles was chosen to represent rising epidemic conditions (FRONTISPIECE) over a fairly large area. It included infestation centers (or spots) ranging in size from 1 to 249 dying pine trees. The foliage color of dying trees is at maximum contrast at this time of year in the Black Hills. We want to know at what scale photo interpreters can determine when endemic conditions become epidemic. Entomologists consider that an epidemic is under way when pine trees begin to die in infestation centers of three to five trees. We can also learn what minimum size area can be detected at each scale and extrapolate what size infestation might be detected from space photographs.

To help us find the infestations on the ground, we used existing 9- x 9-inch aerial photographs on which infestations had been plotted the previous day by aerial observers. By using stereo coverage to facilitate ground navigation, we were able to reduce the ground work considerably over a conventional ground cruise. About 100 spots were checked on the ground by six men to determine the number of killed and discolored trees in each infestation center. Thus, we collected

the "ground truth" to compare later with the results of the photo interpretation.

At each infestation we counted the number of discolored trees, estimated their bole diameters, and measured the area that their projected crowns occupied. We also verified the location of the infestation on the existing aerial photograph. Infestations (mostly single trees) not plotted by the aerial observers were occasionally found on the ground in the course of walking to one of the aerial-plotted spots. These trees were also counted and plotted on the photographs.

AERIAL PROCEDURES

Aerial observation

From earlier work by Heller *et al* (1955) and Aldrich *et al* (1958), we knew that aerial observers could plot about 75 percent of the larger infestations on existing aerial photographs (scale 1:20,000). We used this procedure to speed up the ground work and intensified the coverage by using two observers instead of one on each side of the airplane. All four observers had identical photographs stapled together onto lightweight cardboard for ease of handling in the airplane. We flew the airplane (Aero Commander 500B) at 90 miles per hour and 1000 feet above ground around Study Area II until observers felt that all infestations were plotted. Then, a master set of plotted photos was prepared from the four observers' mosaics; this set was checked once more from the air before being used by the ground crews.

Aerial photography

Two Maurer (KB-8) 70 mm. cameras were used for all aerial photography taken from the Pacific Southwest Forest & Range Experiment Station's

Aero Commander airplane. Two film types (Anscochrome D/200 and Eastman Kodak Ektachrome Infrared Aero (Type 8443))[3] were used simultaneously, exposing both cameras over both study areas. At Study Area I all five attractant sites were photographed in May 1968 and August 1968 at a scale of 1:1,584.

Study Area II was photographed only in August 1968 when pine foliage discoloration was at its maximum. The attempt to simulate near-space photography was made by flying at 16,000 feet above the terrain and by using a short (1-1/2 inches) focal length lens. The following scales of photographs were obtained:

1:7,920	1 inch = 1/8 mile
1:15,840	1 inch = 1/4 mile
1:31,680	1 inch = 1/2 mile
1:63,360	1 inch = 1 mile
1:116,000	1 inch = 1.8 miles

17-Channel multispectral imagery

Our experience with optical-mechanical scanners (Reconofax 11 and RS-7) used on this study during the past two years (1966-67) indicated that the thermal and spatial resolution qualities were inadequate to detect the temperature differences between the dying and healthy trees (4° to 8° C.). From personal communication with Holter and Polcyn (Infrared and Optical Sensor Laboratory, University of Michigan, Ann Arbor), we believed that a trial with their 17-channel scanner

[3] Hereafter in this report Anscochrome D/200 film will be referred to as color film; Eastman Kodak Ektachrome Infrared Aero (Type 8443) will be referred to as infrared color film.

would make the necessary discrimination. One thermal scanner (0.8 to 13.5 microns) has thermostatically controlled temperature reference plates and permits the operator to bracket the reference temperatures within the range of temperatures of the objects of interest on the ground--in this case the dying and healthy trees.

Four time periods of data collection were desired: early morning, midmorning, noon, and early afternoon. We required bright sunshine conditions with less than 30 percent cloud cover. The mission was conducted successfully in four flights over a two-day period; 26 runs were recorded at an altitude of 800 feet above terrain. The multi-spectral airborne sensing instruments (Fig. 4) are shown arrayed inside an Air Force C-47 aircraft on loan to the Willow Run Laboratories.

Airborne data were collected as follows:

Flight No.	Date	Time Period	Reference Temperature Range (°F)	No. of Runs
1	5/29/68	0824-0914	60-70:55-65	7
2	5/29/68	1108-1158	70-80	6
3	5/29/68	1354-1419	70-80	6
4	5/30/68	0709-0849	50-60:55-60	7
				26

INTERPRETATION OF AERIAL IMAGERY

Both study areas (I and II) were examined by three photo interpreters not connected with our project. All project personnel were familiar with the areas, tree locations, and infestation sizes; we did this to avoid bias in our photo interpretation results. The photo interpreters were given color perception tests and training on sample

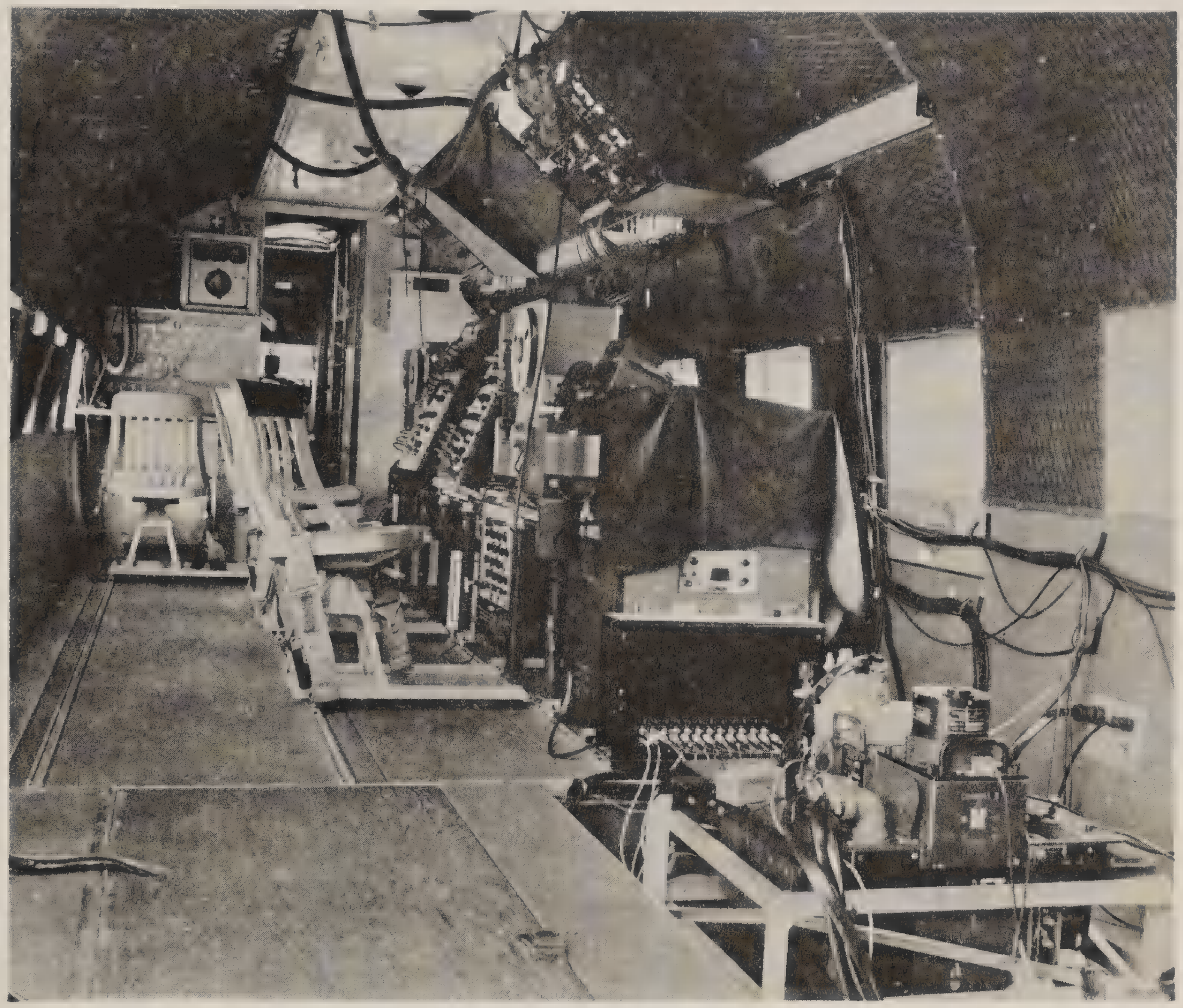


Figure 4.--Interior view of multispectral electronic equipment used by the Willow Run Laboratories, University of Michigan, and mounted in a C-47 type aircraft. Both optical-mechanical scanners are mounted in the floor opening--lower right of picture. All scanner voltage signals are fed to the two magnetic tape recorders shown in the right forward section of the cabin. (Photo courtesy of Willow Run Laboratories, University of Michigan.)

imagery at all scales before beginning work in the study areas.

At this time, we are unable to report on the multispectral imagery because it has not been received from the Infrared and Optical Sensor Laboratory, University of Michigan. Two project scientists are planning to visit Ann Arbor in October to examine the May imagery and to work with the laboratory personnel in optimizing results through multiple-channel playback selection.

On attractant sites - Study Area I

Following their training exercises, each interpreter was asked to identify each dying tree on the color and infrared color film taken in May at a scale of 1:1,584. While viewing the film stereoscopically, they circled each suspected tree on a transparent template which covered each attractant site. The August aerial photographs were interpreted in the same way. The data were analyzed by analysis of variance for three interpreters, two films, two photo dates, and five attractant sites.

On large study area - Study Area II

This area, roughly one by three miles in size, was examined on all five scales (1:116,000, 1:63,360, 1:31,680, 1:15,840, and 1:7,920) and on the two films by each interpreter. The order of interpretation was from the smallest scale (1:116,000) to the largest scale (1:7,920). Interpreters were instructed to circle and number each infestation of newly killed trees on transparent templates; they also counted trees whenever possible within each infestation. The number of templates varied for each interpreter and scale but the reader may comprehend the effect that increasing scale has on the amount of photo handling from the following data:

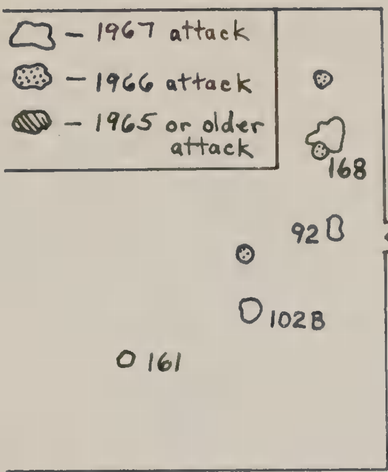
Scale		No. of Flight Lines	No. of Templates
1:116,000		1	2
1:63,360		1	3
1:31,680		2	13
1:15,840		3	27
1:7,920		5	53
	Total	12	98

Examples of the above scales are shown as color stereo prints in Figures 5a and 5b which were made from the color and infrared color transparencies.

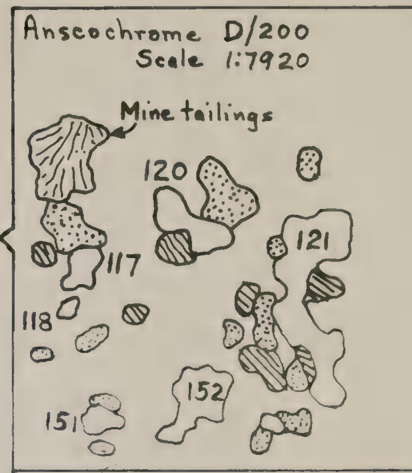
A master base map was prepared from the combined aerial observations and ground checks. The infestations plotted by the photo interpreters were compared then with this base map as to location and tree count. Each interpretation was classified as correct if in the proper location and size, as a commission error if in wrong location or if the trees were killed in prior years to the photography, and as an omission error if the infestation was not plotted at all.

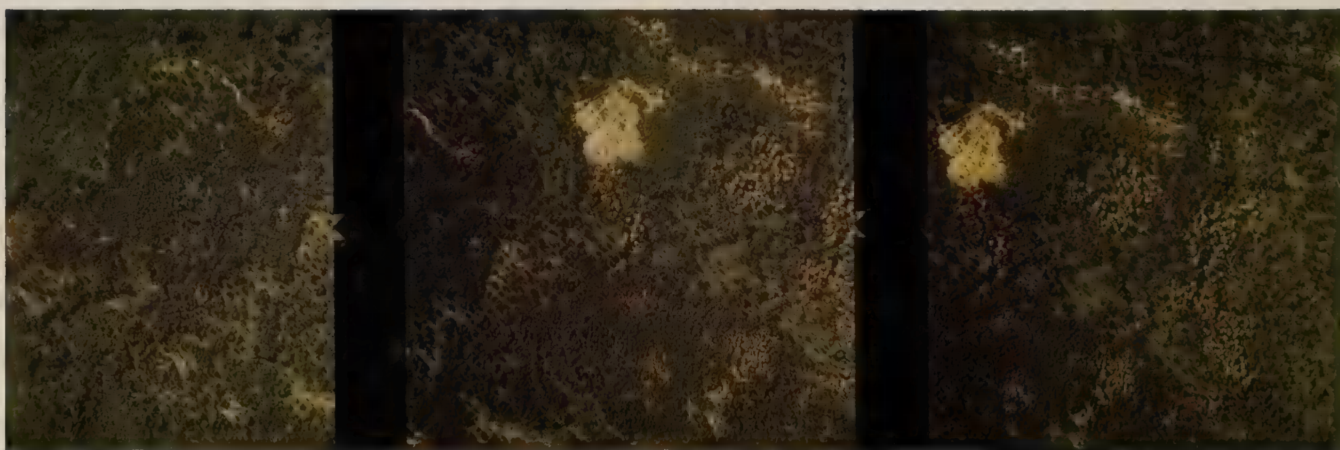
To rectify the interpretation, we had to match the "ground truth" (97 infestations plotted on the base map from ground visits) with the circled spots on each template. This meant about 3,000 comparisons (100 infestations × 5 scales × 3 interpreters × 2 films).

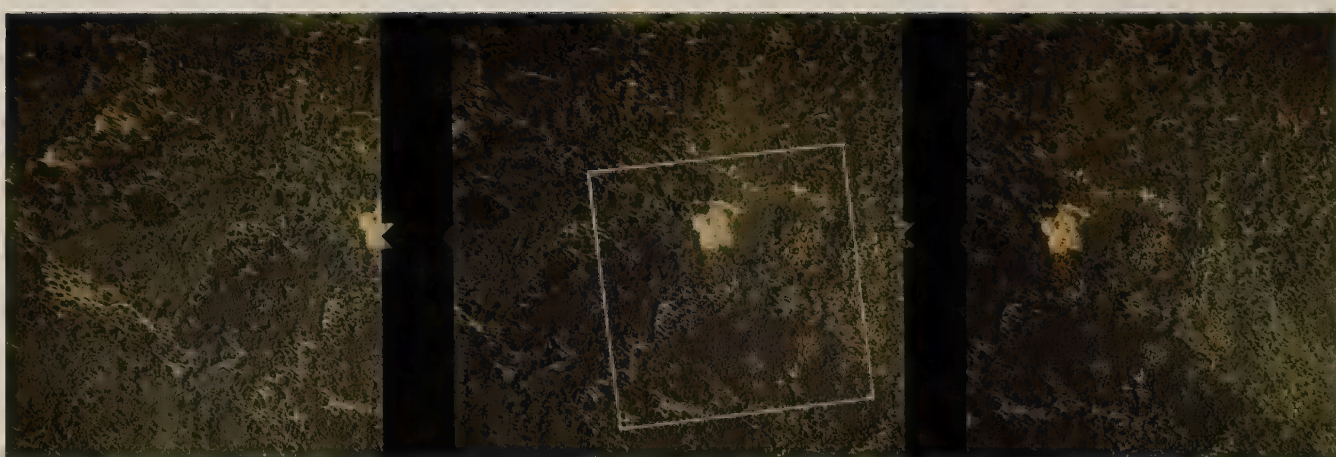
After all scales were examined with a lens stereoscope (2.25× magnification), the photo interpreters were asked to replot and count trees on the smallest scale photographs (1:116,000) when using a Bausch and Lomb Zoom stereo microscope (Fig. 6). We felt that despite

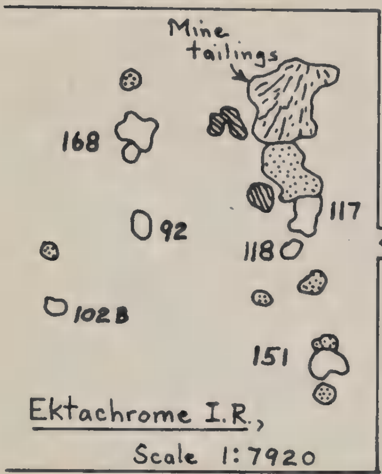


Spot No.	No. of Trees	Largest Dimension(ft.)
92	1	8
102B	17	50
117	41	165
118	8	45
120	82	280
121	249	675
151	81	130
152	177	330
161	1	10
168	11	50









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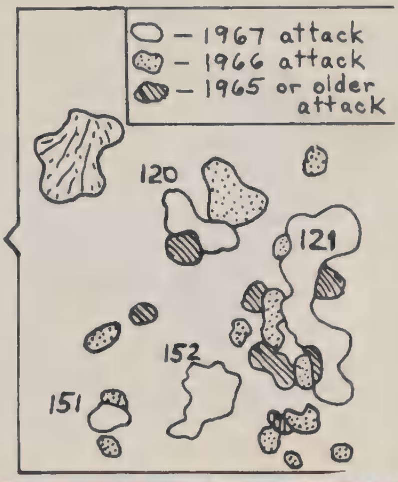


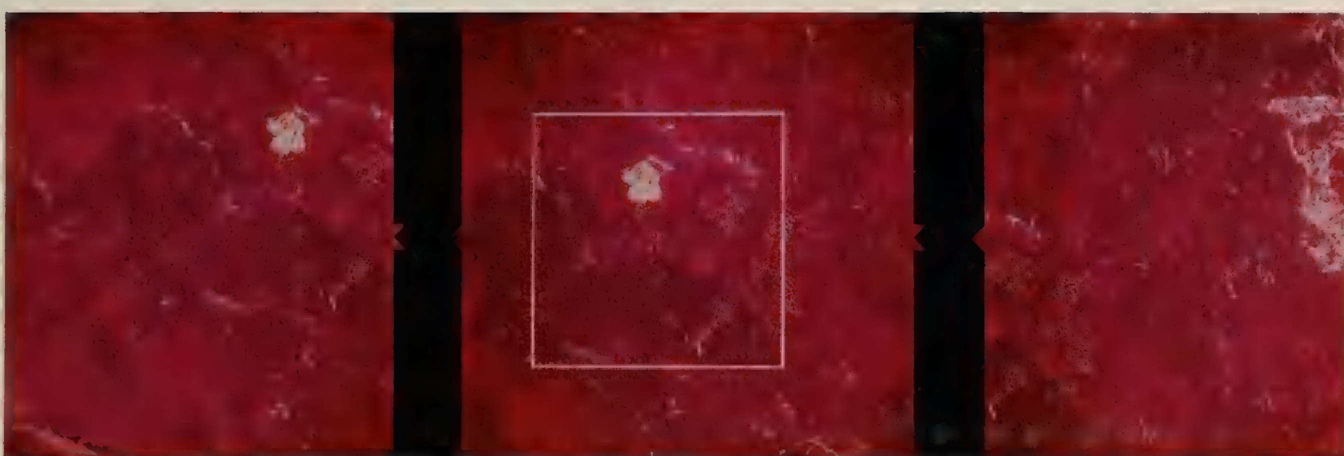
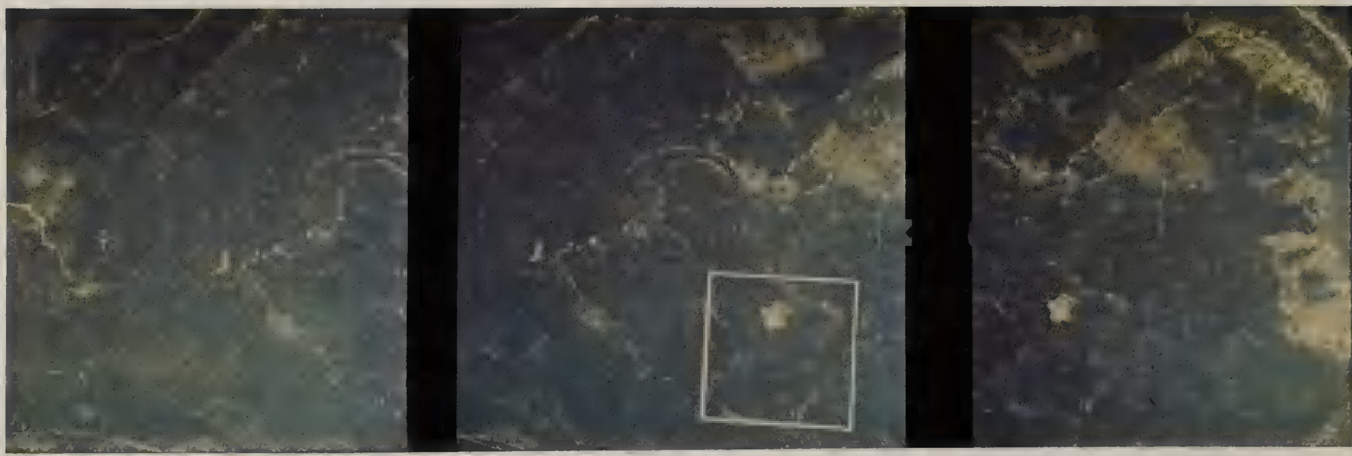


Figure 5a.--Stereo prints made from color (left page) and infrared color (right page) at 2 scales (1:7,920 and 1:15,840). The black and white print at the top of each page indicates the location of several Black Hills beetle infestations. The number of new faders and the largest dimension of each infestation is shown in the table in the center. The coverage of the center photograph of the largest scale is etched in white on the smaller scale. These photos were taken August 18, 1968, with a 150 mm Schneider Xenotar lens. In August about 80 percent of the currently dying trees have yellow to yellow-red foliage on the color photographs. On the infrared color prints the same trees appear light pink, to white and yellow. Trees killed one year earlier are easily confused with recent kills; they appear dark yellow-red on color film and yellow on infrared color.



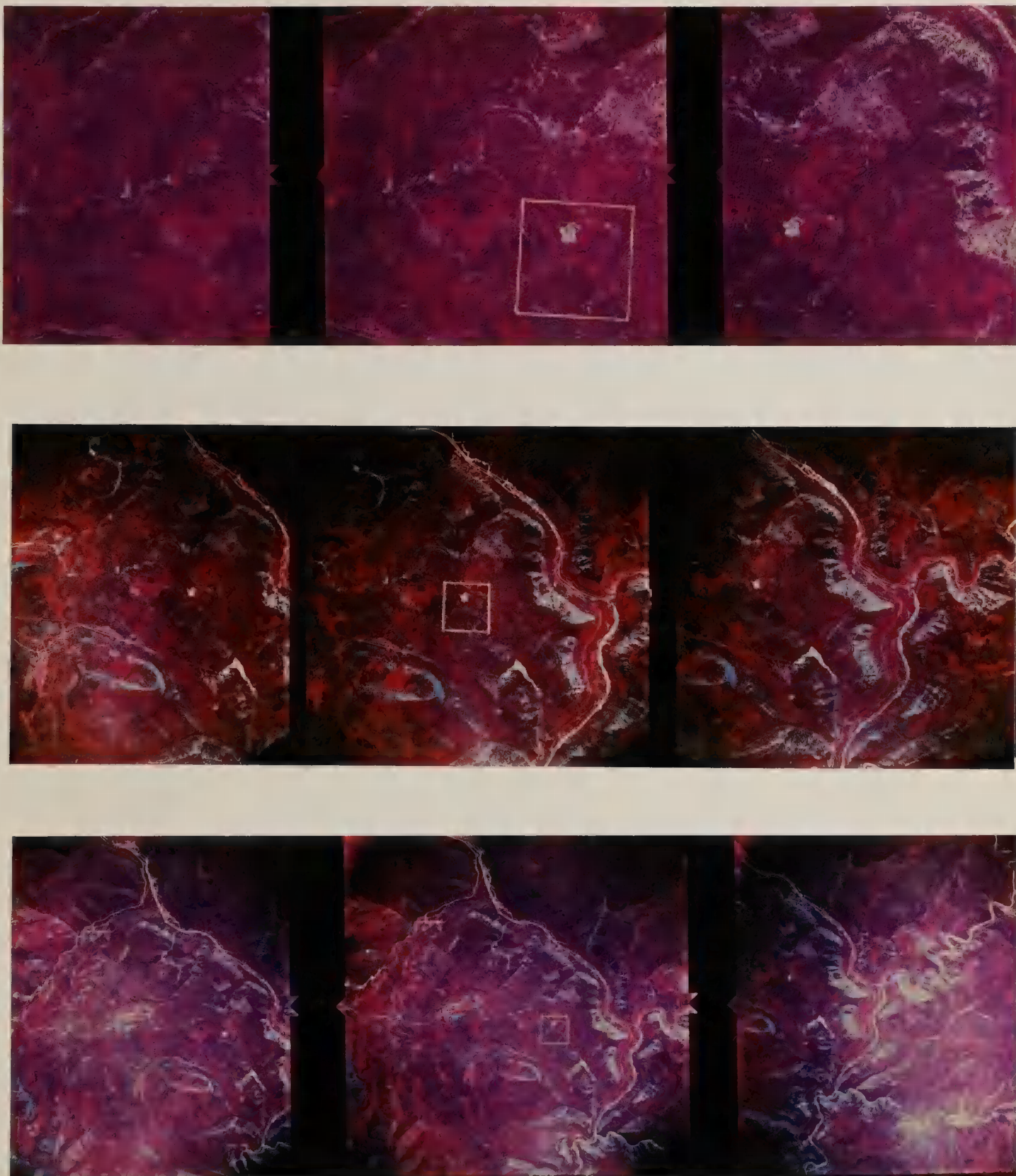


Figure 5b.--Stereo prints made from color (left page) and infrared color (right page) at 3 scales (1:31,680, 1:63,360, and 1:116,000). The largest scale was taken with a 150 mm Schneider Xenotar lens on August 8, 1968. The smaller scales were taken with a 38 mm Biogon lens on the same date. The small etched square refers to the coverage of the center photograph of the largest scale (1:7,920) in Figure 5a.

Figure 6.--Bausch and Lomb Zoom stereo microscope was used to interpret small-scale color and infrared color transparencies (1:116,000). Magnifications used by the three photo interpreters varied from 12x to 28x.

bias from looking at the large-scale photographs earlier, we should get an indication of the accuracy and improvement to be expected with stereo magnification. Such data should indicate infestation sizes which might be resolved from space photography.

RESULTS

GROUND MEASUREMENTS

Physiological

The results of ground data collected May 29-30, 1968, on attractant site 67-3 are shown in Figure 7. These data cover the period of time when the overflights by the University of Michigan C-47 aircraft were made. The apparent emittance temperatures taken with the PRT-10 near the resolution target are shown in Table 1.

The departure of foliage emission-temperature curves between healthy and attacked trees, as previously stated (Heller _et al_, 1966-1967), is strongly related to solar radiation intensity, wind speed and needle moisture tension. The maximum temperature difference recorded by a ground-based radiometer during a flight mission was 4.5° C., although differences of 7° to 8° C. were measured at other sampling times.

Needle moisture tension, as measured with a hydrostatic pressure bomb (Fig. 8), still provides the most sensitive measure of tree vigor at any point in time. Figure 7 shows the close relation between needle moisture tension, solar radiation, wind speed, vapor pressure deficit, and internal water movement. Previous work by Weber and Olson (1967) also showed the additional strong relation to soil moisture availability.

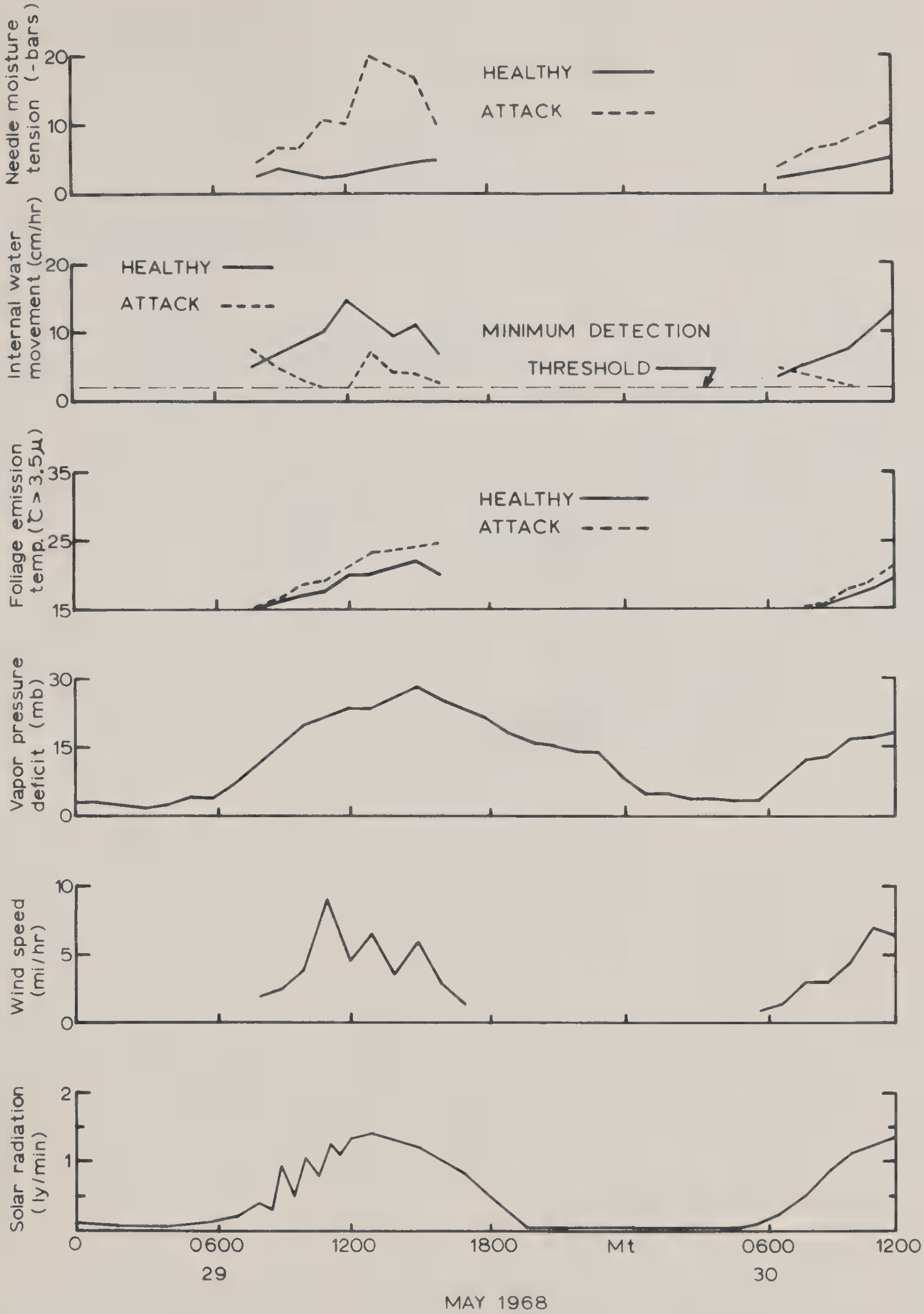


Figure 7.--Meteorological and tree physiological data collected at ground instrumented test site 67-3 for the period May 29 and May 30, 1968. The sampling intervals cover the period during which over-flights were made with the University of Michigan C-47 aircraft, with the 17-channel scanner system.

TABLE 1

EMITTANCE TEMPERATURE - °C

BARNES PRT-10

Instrument Vertically Oriented (dist. to target - 1 7/8")

Date	Local Sun Time	Resolution Target Black	Resolution Target Alum.	Grass	Exposed Soil	Comments	Air Temp °C
5/29/68	0816	29	4	7	10	overcast--very faint to no shadow	22
	0819	25	4	9	10	overcast--very faint to no shadow	22
	0824	43	22	22	26	overcast--very faint to no shadow	22
	0827	31	19	18	22	overcast--no shadow	21
	0831	30	17	19	20	overcast--no shadow	21
	0844	53	15	27	28	sun bright	21
	0849	34	16	20	24	cloudy--no shadow	21
	0859	47	16	22	26	sun bright/a few clouds	21
	0911	58	16	26	31	sun bright	20
	0916	50	11	26	30	a few clouds	20
5/29/68	1108	45	7	32	40	clear	24
	1114	55	5	27	35	clear	24
	1120	57	7	32	36	clear	25
	1126	58	11	34	37	clear	25
	1152	54	8	34	37	clear	26
	1158	55	14	27	37	clear	26
5/29/68	1354	48	7	27	42	clear/cu. to south	28
	1400	48	8	29	38	clear/cu. to south	28
	1405	45	10	29	37		28
	1406	51	10	27	37		28
	1412	50	7	27	39		28
	1419	40	11	27	37		28
						rain during evening 5/29-30/68	
5/30/68	0709	28	10	12	18	clear (water drops on alum., small puddles on branches)	18
	0717	32	10	14	23	clear	20
	0723	30	9	11	20	clear	20
	0729	31	10	10	20	clear	20
	0735	22	9	8	14	clear	20
	0749	38	15	19	26	clear	22

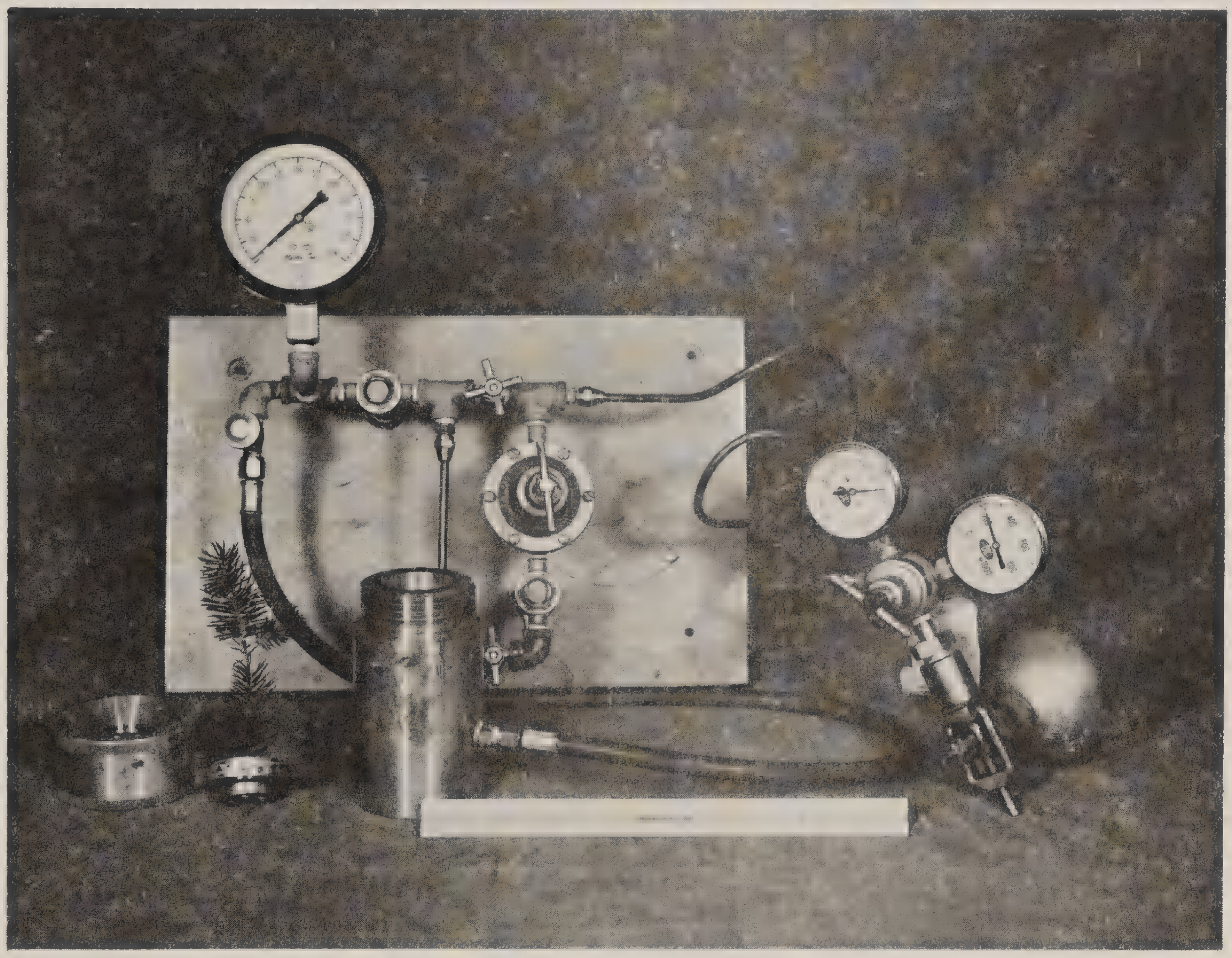


Figure 8.--This hydrostatic pressure cell with pressure manifold is taken into the field to measure leaf moisture tension. Data from the pressure cell are closely related to moisture stress conditions and general tree vigor.

The interdependency of physiologic functions on physical environment is shown in Figure 7. Increasing values for solar radiation are associated with increasing values for water movement within the trees and needle temperature. For example, dying trees have less effective water conduction systems (due to development of blue-stain in the xylem cells) and cannot provide enough water to the transpirational sites in the foliage. This causes high midday values for needle moisture tension. Needle moisture tension is an expression of water shortage in the leaf cells, and as stated is an important indicator of a tree's well-being. We feel that the large moisture gradient that exists between the leaf cells of attacked trees and the atmosphere is important for detection of moisture stressed trees, especially in the 2.2 to 2.6 micron band. This band appears most useful, according to previous greenhouse work, for detection of moisture loss. However, it does not necessarily follow that because of the moisture stress and general decrease in physiologic activity, including carbon dioxide assimilation, attacked trees can also be separated by employing a CO_2 absorption band detector. Even under the best conditions, the CO_2 gradient between the leaf cells and the atmosphere is many times smaller than the moisture gradient.

In the case of both healthy and attacked trees, there is a normal tendency for increasing values of needle moisture tension at midday under full sun. This is caused by the normal inability of the tree to get water rapidly enough from the soil through the tree to the foliage. This phenomenon is called midday transpirational lag.

Indications are that on May 29 and 30 soil moisture conditions were favorable for normal tree functions. This, together with the existing stage of blue-stain and beetle development, permitted the attacked trees to recover each night from the high moisture stress condition from the previous day. Because of favorable soil moisture, both stressed and unstressed trees had very similar sap flow rates and needle moisture tensions early each morning. However, shortly after sunrise their rates of physiologic function varied considerably and these ultimately produced the midday thermal difference.

Calculations of vapor pressure deficit were added this year, and as might be suspected, were closely correlated with internal water movement and needle moisture stress. Actually, vapor pressure deficit is most closely correlated to rate of transpirational water loss as shown in our greenhouse studies. But to date, there is no reasonable means of monitoring transpirational water loss in the field directly on large trees. However, we feel satisfied with the results of the indicator values--vapor pressure deficit, internal water movement and needle moisture stress.

Comparison of Munsell colors on discolored foliage - seasonally and annually

The same individual, W. F. McCambridge, made all Munsell color chip comparisons for both 1967 and 1968. Therefore, the results show the true hue differences of the foliage and are not subject to observer bias.

The Munsell notations were very similar in the percentage calls of hue, value and chroma for both years (Fig. 9). In 1967, there were 256

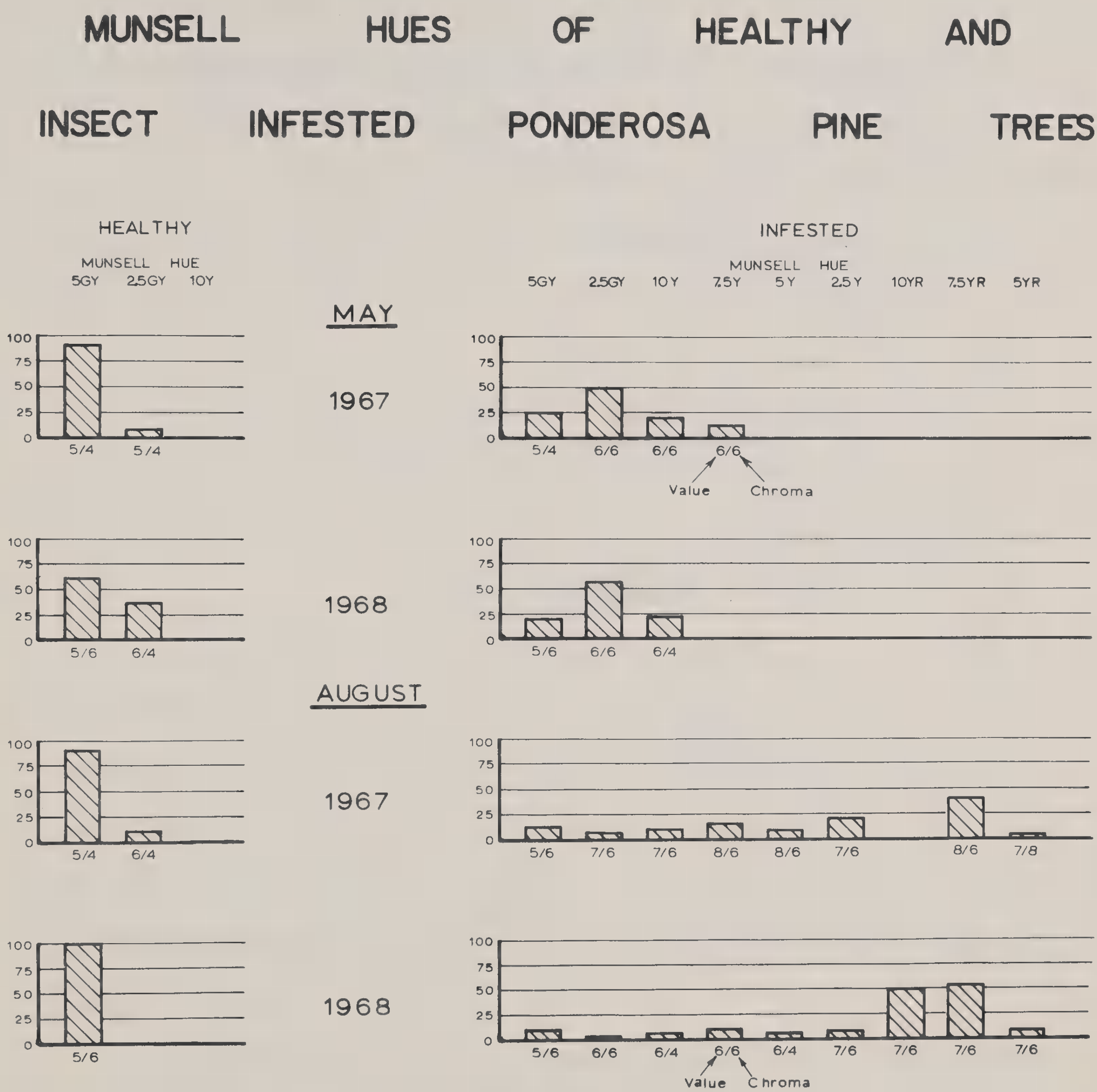


Figure 9.--Average hue, value, and chroma notations of healthy and dying ponderosa pine foliage made by one ground observer over two seasons (May and August) and two years (1967 and 1968). Note the similarity of the healthy foliage calls. In August 1968, more of the foliage was yellow-red (10 Yr and 7.5 Yr) than in the previous year. The numbers under each bar chart refer to the average value (lightness) and chroma (color strength) of the pine foliage.

trees rated; in 1968--165. The precipitation during the fall of 1967 and spring of 1968 was less than the similar period in 1966 and 1967. This lowered precipitation induced the dying foliage to dry out more than the foliage dying the previous year. In turn, this moisture loss is reflected in the Munsell hues which shifted more to the yellow-reds in 1968--the drier year. Note the remarkable consistency in calling the values and chromas for both the healthy and dying foliage for both seasons and years; they are not more than one value or chroma index removed for each hue. The values and chromas are shown in Figure 9 under each block representing the percentage of hue calls.

EVALUATION OF AERIAL OBSERVATION AND AERIAL PHOTOGRAPHY

Aerial observation

The most useful purpose served by the aerial sketch-mapping survey was to delineate the intended study area. We recognized that there are problems encountered with this technique, e.g., mediocre plotting accuracy and large variation in the number of trees counted per spot between observers. However, during these flights, we had ideal weather conditions and most trees were in an advanced stage of visual fading.

It was necessary to fly two sketch-mapping missions before being able to resolve the final location of all detectable spots within Study Area II. The first mission was flown with four observers over the entire area. The second and shorter mission was flown with two of the first four observers to resolve discrepancies between observations from the first flight. For these reasons, it is difficult to subject the visual observations to any valid type of statistical

comparison with ground results or even photo interpretation results.

Of the 97 spots that actually were found to exist in the area, the combined plotting of all four interpreters resulted in their locating 98 percent of the spots. Individually, observers had a plotting accuracy ranging from 37 percent to 70 percent of the 97 infested spots. Mean observer accuracy was 55 percent. One interesting point is that any two observers would have plotted 80 percent of the infested spots correctly.

Again, as in the past, when we have conducted such tests, observer experience was directly related to plotting accuracy as well as estimating numbers of trees per spot. The observer who attained the highest plotting accuracy has been a member of aerial sketch-mapping crews on numerous missions over the years. In addition, he is very familiar with the particular area of the Black Hills where Study Area II is located. The man with the lowest plotting accuracy was flying his first aerial sketch-mapping mission, and it was worthy of note that by the end of the mission his accuracy had improved.

In spite of the advanced fading of the attacked trees within Study Area II, there was a consistent underestimate of the numbers of infested trees per spot located by the aerial observers. There were rare instances of overestimates.

The ground tally showed an average of 17 trees per spot, while the four aerial observers averaged 8 trees per spot. The experienced observers counted, on the average, 10 trees per spot against the less experienced who counted only 6.

Again, this experience shows, as in the past, that the value of

aerial sketch mapping lies not in the derived estimates of trees, but in delineating an infestation. There are more efficient and accurate methods of locating bark beetle spots and in estimating the numbers of trees in a spot.

Photo interpretation

On attractant sites - Study Area I

The results of the photo interpretation for 5 attractant sites at Study Area I substantiate the results discussed in the September 1967 progress report. For instance, the percentage of discolored trees, as rated by the ground observer, increased from May to August. A similar progression was present in the photo interpretation results.

There were no significant differences between film types (color and infrared color film) or between interpreters. However, differences between attractant sites and seasons of photography were significant.

Comparison of photo interpretation with ground observations at each photo period is illustrated in Figure 10. On May photography, interpreters were calling about 60 percent of the faders correctly. Omission errors, i.e., not calling a dying tree a fader, amount to about 40 percent. Commission errors--calling healthy trees suspected faders--were as high as 45 percent at this time.

On August photography, about 90 percent of the faders were called correctly. Omission errors and commission errors both dropped to about 10 percent. Interpretation was slightly better from the 1967 transparencies because photo interpreters were more familiar with the appearance of Black Hills beetle damage on transparencies.

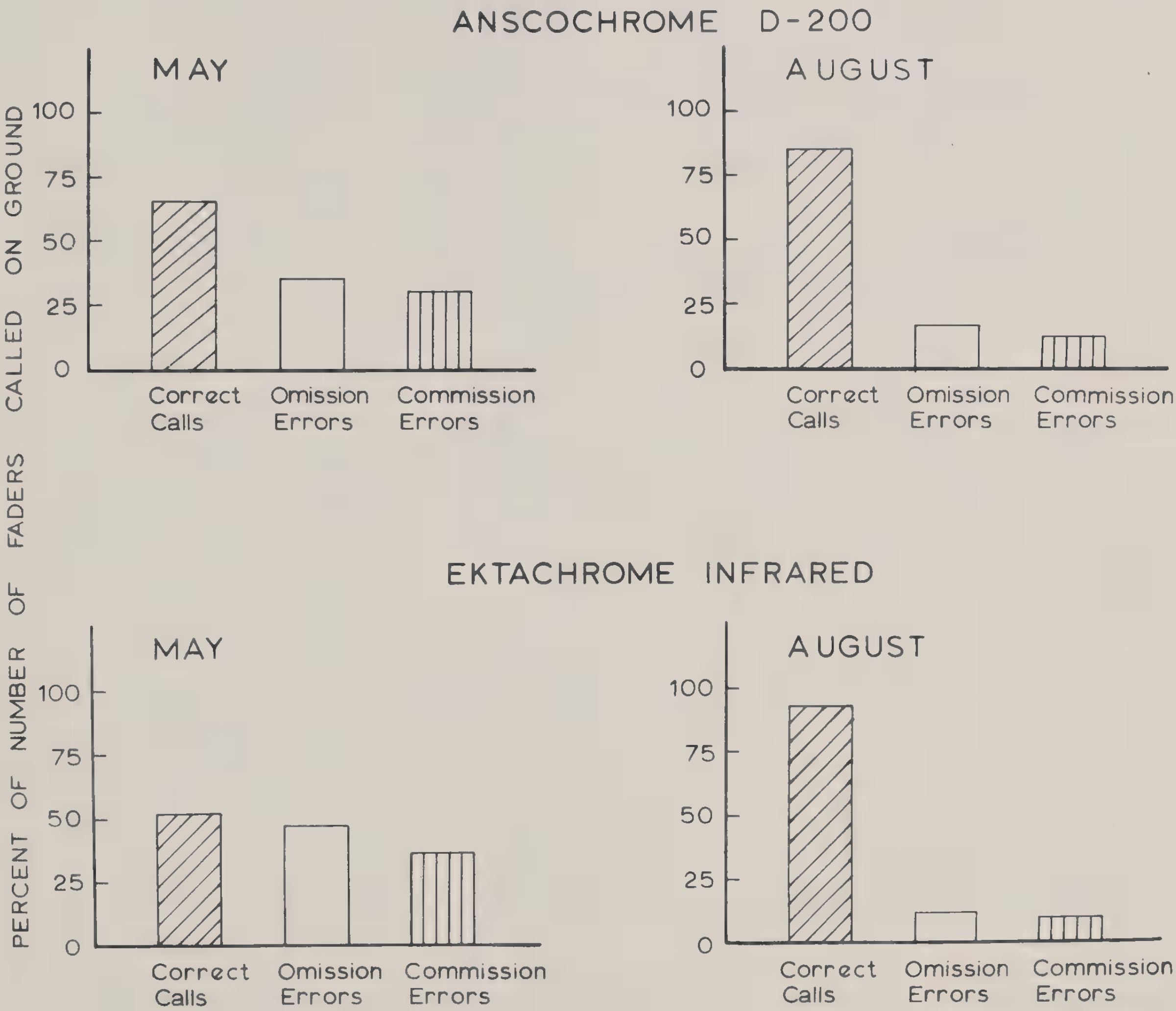


Figure 10.--Comparison of interpreter results for all plots during May and August on color and infrared color film. Note that the percentage of correct calls is higher in August than in May. Also note that the frequency of omission and commission errors is also reduced in August.

The relatively high instance of commission errors this year by photo interpreters may be due to their inexperience with large-scale aerial photography and the photo subject, i.e., beetle-infested trees. Further examination of this problem may help us to find an answer to the perennial question of how to train inexperienced interpreters to recognize the photo characteristics of dying trees. This is a subject that receives too little attention in the remote sensing program.

On large study area - Study Area II

Entomologists have found that when Black Hills beetle infestations begin to appear in small groups, a change from endemic to epidemic conditions is imminent. Thus, to detect a potential insect build-up of epidemic proportions, aerial sensors flown at conventional altitudes or from space orbit must resolve these small infestation centers.

Within our study area we found 48 centers of 1 to 3 trees in size--almost one-half of the 97 active bark beetle infestations (Fig. 11). The distribution of infestations by size classes is tabulated below. The average dimension of the infestations in each class is also shown.

Size class (number of trees)	Number of infestations	Average of largest dimension (feet)
1 - 3	48	16.7
4 - 10	18	41.6
11 - 20	12	79.6
21 - 50	12	182.2
51 - 100	4	171.2
100 +	3	445.0

Figure 11.--Study Area II enlarged from a 1:116,000 scale Kodak Ektachrome Infrared Aero transparency. Adjoining base map shows infestation locations as plotted on ground. Some of the larger infestations can be distinguished on the stereo prints shown in Figure 5a and 5b even on the smallest scale photographs.

Single trees and infestations up to 3 trees in size are detected with the greatest success on infrared color at the three largest scales (Fig. 12). As expected, the larger the scale the greater the success. Maximum accuracy for the 1 to 3 tree class is 79 percent on 1:7920 scale infrared color. On the 1:31,680 scale infrared color, detection success is only 50 percent. The number of successes is reduced rapidly when scale is smaller than 1:31,680. For example, at 1:63,360 the best detection is 7 percent on color film.

If we can afford to wait until infestations become 4 to 10 trees in size, detection will improve considerably (Fig. 12). Almost 95 percent of the infestations are detected on 1:7920 and 1:15,840 scales. There appears to be no difference between infrared color and color film at these scales. However, as the scale becomes smaller, color film improves detection. For instance, on 1:63,360 scale color 37 percent of the infestations are detected. Only 20 percent are detected on infrared color of the same scale. On 1:116,000 scale photographs, which we have used in this test to simulate space photography, only 9 and 7 percent of the infestations can be detected on color and infrared respectively.

When the 1:116,000 scale photography was examined with a Zeiss Zoom stereo microscope, detection was improved (Table 2). Although these data are impressive, it should be pointed out that this portion of the test was conducted after the interpreters had scanned the area many times while completing the other interpretation. Despite attempts to remove bias, the interpreters were undoubtedly attracted to locations where they had observed infestations on larger scales. These

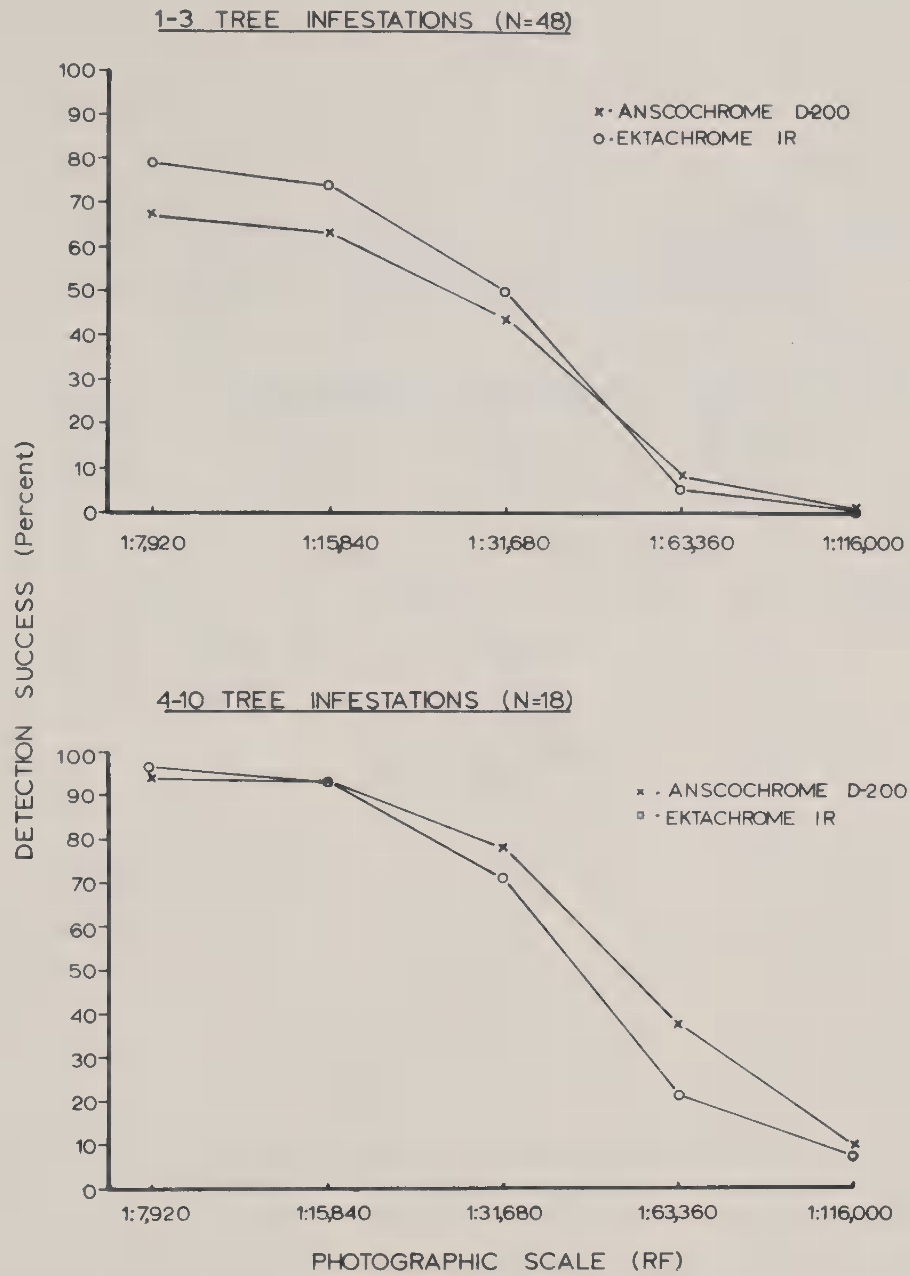


Figure 12.-- Successful detection of small bark beetle infestations expressed as a percent (mean) for three photo interpreters on two films and at five photographic scales. The upper graph shows success in detecting infestations of 1 to 3 trees in size. The lower graph shows success in detecting 4 to 10 tree infestations. Notice the increase in detection success for the larger infestations.

Table 2. Comparison of infestation detection in percent[1] on 1:116,000 scale color and infrared color transparencies; with and without a Zeiss Zoom stereo microscope

Infestation Size Class	Number of spots in Size Class[2]	Detection on color film		Detection in infrared color	
		Without stereo microscope	With stereo microscope	Without stereo microscope	With stereo microscope
Trees		Percent		Percent	
1-3	48	0	6	0	15
4-10	18	9	46	7	50
11-20	12	19	67	23	92
21-50	12	48	67	53	67
51-100	4	68	92	83	92
100 +	3	67	89	90	100
	97				

[1] Average of 3 photo interpreters.

[2] As found by ground survey.

results, though not conclusive, are very encouraging and this test should be repeated with other interpreters.

It is quite common to refer to the capabilities of remote sensors in earth orbit in terms of the smallest objects that can be resolved. Because of this, the largest dimension of each of the infestations was measured on the ground to compare detection success with infestation size. Through this comparison we should find the resolution requirements for detecting bark beetle infestations.

The tabulation below shows the distribution of the 97 infestations by four size classes. Also of interest is the average number of trees found in each of the classes on the ground.

Size class (feet)	Number of Infestations	Average number of trees
0-20	40	1.6
21-50	23	5.3
51-100	13	13.9
101 +	21	62.2

From this we can see that to detect infestations of 3 trees with any success, sensors must be able to resolve objects or spots (groups of like objects) 20 feet in the largest dimension. The reported capabilities of remote sensors at orbital altitudes are no better than 100 feet. With 100-foot resolution we could expect to detect only infestations averaging 14 to 62 trees in size. This would be of little help in discovering build-up of beetle populations to epidemic proportions.

The three interpreters used in this study were able to detect 68 percent of all infestations over 100 feet in dimension on 1:116,000 scale infrared color film (Fig. 13). On color film, detection was only 57 percent. No infestation less than 20 feet in dimension was detected on either film at this scale.

Detection success on other photographic scales followed the same pattern as presented in the previous discussion on numbers of trees by various sizes of groups. The larger the scale the better the detection. Infrared color resulted in better over-all detection on the three largest scales. Color film gave slightly better discrimination between infestations and their surroundings on the smaller scales and resulted in higher detection success.

Using the Zeiss Zoom stereo microscope, the three interpreters again were able to improve detection of all size classes (Fig. 14). Considering only infestations larger than 20 feet in dimension, 55 percent were detected on the color film and 65 percent on infrared color. This is an increase from 25 and 29 percent respectively for interpretation without the Zoom stereo microscope or a gain of over 100 percent.

Unfortunately, along with greater detection success on larger scale photographs we also have a higher rate of commission errors (Table 3). These errors are caused by calling old faders and other anomalies in the forest as new faders. In the present study, birch trees in the area were discolored (brown) from a leaf mining insect and our inexperienced interpreters called many of these as bark beetle infested trees. This seemed to be a greater problem on the larger scales. As

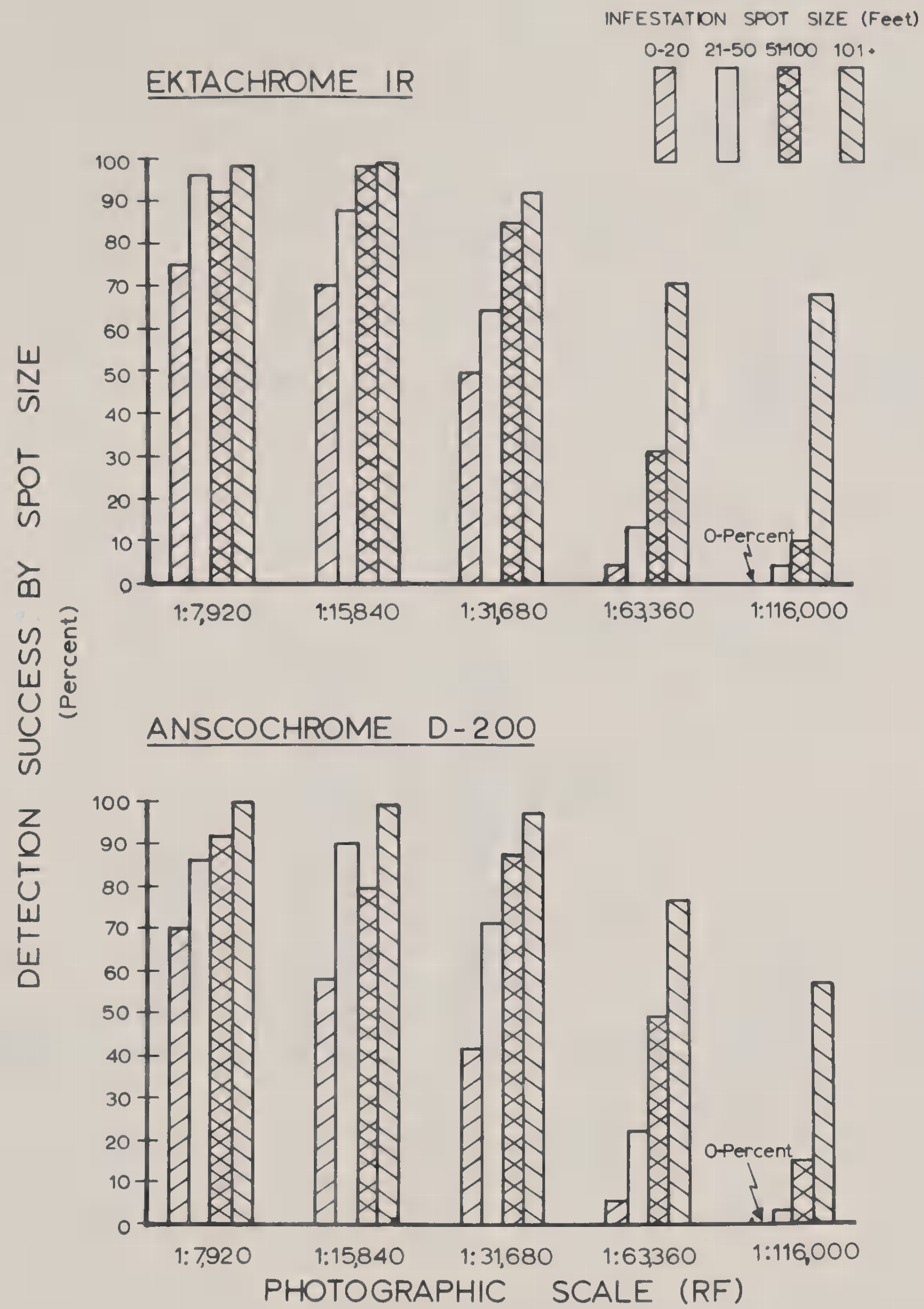


Figure 13. Detection success (mean of three interpreters) expressed as a percent for four infestation size classes, five photographic scales and two films. The upper bar chart shows detection success on infrared color film and the lower bar chart shows detection success on color film. Notice that detection is better on infrared color at the larger scale (1:7,920, 1:15,840 and 1:31,680). On the smaller scales (1:63,360 and 1:116,000) used to simulate a space photograph, detection is greater for all infestation sizes using color film.

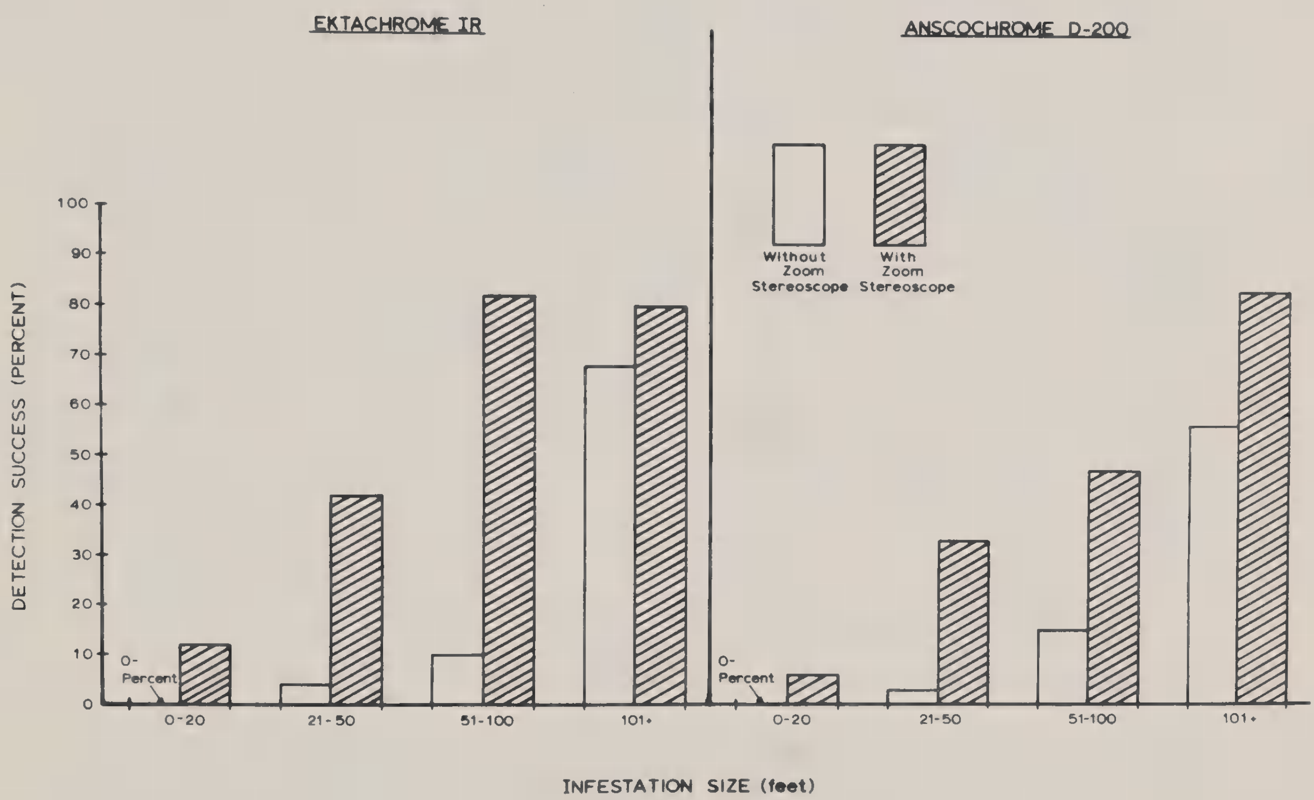


Figure 14.--Mean detection success (in percent) for three interpreters on 1:116,000 scale color and infrared color transparencies with and without the aid of a Zeiss Zoom stereo microscope. Infestation size is expressed in terms of the largest dimension in feet.

Table 3. Number of commission errors[1] by interpreters, photo scale and film emulsion

Photograph Scale (RF)	Number of Errors							
	Anscochrome D/200 Interpreter				Ektachrome IR Interpreter			
	1	2	3	Mean	1	2	3	Mean
1:7,920	38	52	42	44.0	46	36	47	43.0
1:15,840	81	35	26	47.3	43	34	42	39.7
1:31,680	21	17	15	17.7	19	12	13	14.7
1:63,360	1	0	2	1.0	1	0	4	1.7
1:116,000	7	1	0	2.7	1	0	0	0.3

[1] A commission error is made when old insect-killed trees, exposed soil, rocks, and other anomalies in the forest are called a new insect infestation.

scale became smaller, hardwood-pine type differences were more apparent and fewer errors of this kind were made.

There is apparently no significant difference in number of commission errors due to the type of film used. However, there is a difference by photograph scale--the larger scales having more errors of the commission type than the smaller scales. It appears that the best compromise between detection success and commission errors will result from using 1:31,680 scale photographs--color or infrared color.

SUMMARY

A short summary of the significant findings of the tree physiology and photo interpretation results follows:

TREE PHYSIOLOGY

A summary of the important tree physiology results can be stated as follows:

1. Emitted temperature differences, as measured on the ground, are important to the calibration of airborne thermal imagery.

2. Rate of transpirational water loss is an important contribution to the variation in emitted temperature measurements.

3. Vapor pressure deficit of the atmosphere, soil moisture availability, and solar radiation are important components for controlling transpiration.

4. The rate of internal water movement and needle moisture stress are highly correlated with transpirational water loss and the resultant foliage temperatures. They are good indicators of relative tree vigor when plotted over time.

5. Wind speed appears to be an important determinant of thermal discrimination of attacked trees when measured at over 4.5 to 5 m.p.h. This phenomenon shows less consistency than other indicators.

PHOTO INTERPRETATION

As a result of the photographic film and scale test reported here, we can make several observations of importance regarding detection of Black Hills beetle infestations.

1. Detection success on 1:15,840 scale photography is slightly less than on 1:7,920 scale photography. Commission errors are approximately the same on both scales--almost 50 percent of the total infestations detected.

2. A scale of 1:31,680 can provide a balance between detection success and commission errors at much less cost. With the exception of infestations 1 to 3 trees in size, detection at this scale is almost as good as it is at the larger scales. Commission errors are less than half the number on the larger scales.

3. Infrared color film is better than color for detecting small infestations 1 to 10 trees in size on 1:7,920, 1:15,840, and 1:31,680 scales.

4. There is no difference between color and infrared color for detecting infestations larger than 10 trees.

5. Infestations of 1 to 10 trees cannot be detected with sufficient accuracy on 1:116,000 scale photographs. With the aid of a Zeiss Zoom stereo microscope, approximately 50 percent of the infestations in the 1 to 10 tree class can be detected. With magnification, infrared color is slightly better than color but the number of commission errors is increased.

6. Approximately 68 percent of infestations over 100 feet in size can be detected on 1:116,000 scale infrared color film. On color film, only 56 percent of these infestations can be detected. This may be improved with the aid of a Zeiss Zoom stereo microscope.

FUTURE COST-BENEFIT ANALYSIS

Because of the wealth of information available on the pilot Study Area II, it seemed appropriate to propose further analysis of the photo interpretation data as it relates to cost benefit. For example, the cost of measurement of ground and photo plot data and population variance data will be analyzed to determine optimum sampling designs.

The questions to be answered are:

1. For each of a series of fixed costs, what combinations of numbers of ground and photo plots yield the estimate having lowest variance for each scale of photography? For what scale is this variance a minimum?

2. For a fixed variance what numbers of photo and ground plots and at which scale of photography yield the lowest cost?

3. Can we extrapolate from the photo data on hand to find the probable accuracy obtainable at altitudes approaching those of satellite photography?

4. To what degree would our estimate be biased using Langley's very efficient multiple-stage variable probability sampling with large-scale photography? Does this method, using measurements of groups of trees rather than plots, yield a cost advantage over plot measurement sampling designs?

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APPENDIX

The following is a list of Forest Service, U. S. Department of Agriculture, personnel who have made contributions to this research study and represent a major salary contribution to it:

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